Broadband Quantum Noise Reduction in a Small-Scale Suspended Interferometer with Quantum Entangled Squeezed Beams

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Abstract:

General relativity predicts the existence of gravitational waves (GWs), ripples in spacetime that are now observable to highly sensitive interferometers. However, quantum noise poses a significant challenge for gravitational wave (GW) interferometers, influencing the entire bandwidth range (10-10,000 Hz) of the current GW detectors. At higher frequencies, shot noise (SN) predominates, while at lower frequencies, radiation-pressure noise (RPN) becomes the limiting factor, reducing both sensitivity and measurement precision. Squeezing techniques are implemented to address this issue by confining uncertainty within one quadrature of the light field [3]. Starting from the observing run O4 Virgo and LIGO have enhanced this method through FrequencyDependent Squeezing (FDS) [1, 2]. By employing a 300-meter-long detuned filter cavity, the squeezing ellipse is rotated, allowing phase squeezing at high frequencies to reduce and amplitude squeezing at low frequencies to mitigate RPN, ultimately refining detection capabilities across the frequency spectrum [4]. A promising alternative technique to reduce quantum noise across the entire sensitivity band uses Einstein-Podolsky-Rosen (EPR) entanglement. This approach involves injecting two entangled beams at different frequencies into the dark port of the interferometer, enabling it to act as both a filter cavity and a gravitational wave detector. The Suspended Interferometer for Ponderomotive Squeezing (SIPS) adopts a large-scale GW detector layout, with a Michelson configuration and Fabry-Perot arm cavities. This system was initially thought to generate FDS in the GW frequency band using the ponderomotive technique [6, 7]. To enhance stability, a precise local control system was developed for the main optics of SIPS which are suspended in a double pendulum configuration with monolithic fibers to reduce thermal noise. Advanced PXI-based data acquisition and position-sensitive detectors (PSDs) monitor angular and linear displacements, while real-time signal processing in LabVIEW enables corrective actuation, marking a significant step toward improved alignment and noise reduction in GW interferometry [6]. The talk highlights the status of SIPS, focusing on the local control strategy, underscoring its potential impact on the field.